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Summary Sheet

Mechanisms and Data Driven Hybrid (MDDH) Food System Model Optimized for Equity and Sustainability

Summary

Nowadays, our global food system is unstable partly due to the massive national and international food producers and distributers. Additionally, food insecurity and environmental problems are becoming increasingly severe under the current food system. Therefore, it is of significant importance to optimize the food system for various levels of efficiency, profitability, sustainability and equity.

In this article, we analyze the food systems of different countries in the world. First, we divide countries into three types through cluster analysis: suitable for agriculture, moderately suitable for agriculture and unsuitable for agriculture. Next, we have established a mechanism model of food including four subsystems: production, supply-chain, consumption and decomposition. Besides, we consider the driving factors in the system and establish a one-to-one correspondence with the subsystems to evaluate the four indicators of the system. We establish four linear equations respectively, and then through the equivalent transformation and normalization of the evaluation indicators, we obtain the Mechanisms and Data Driven Hybrid (MDDH) Food System Model. The input vector, output vector and Driving Matrix of the model correspond to the mechanism model, evaluation indicators and driving factors of the food system respectively. Through simulation, we divide the food systems of different countries into three categories: traditional food systems, moderate food systems and modern food systems.

In order to pursue the sustainability and equity of the system, we optimize the MDDH Model through a single-objective optimization model to obtain the Optimized for Equity and Sustainability (OES) Food System Model. And by modeling the food systems of developing and developed countries (taking China and the United States as examples), we find that the sustainability and equity of the optimized system have been significantly improved. In addition, under ideal circumstances, profitability and efficiency will be slightly improved, but considering actual factors, the profitability and efficiency of the optimized model will be affected to varying degrees, depending on the development level of factors such as technology and economy in different countries and the macro-control of social policies. In order to estimate the time of benefit of the optimized system, we establish the Gray Forecast Model through two quantitative indicators of environmental factors and the incidence of malnutrition, and conclude that it takes at least four years for the benefits and costs to occur in developed countries and at least nine years in developing countries.

Finally, we analyze the scalability and adaptability of the model, and compare the three types of countries in the cluster mentioned above. The food systems of each type of countries are similar. Besides, we change the parameters of *Trade Food* and food waste rate for sensitivity analysis of the model, and find that our model has good stability.

Keywords: food system, sustainability, equity, mechanism model, data-driven model

Contents

1 Introduction

1.1 Restatement

Nowadays, relevant data has shown that the world food system is unstable and it is partly a result of our current global system of massive national and international food producers and distributers. Most countries and regions are still pursuing profitability and efficiency as the leading factor of the food system. Despite this, there are still many countries and regions in the world, including some developed countries, with large populations suffering from hunger. Paradoxically, about one-third of the food produced for human consumption in the world every year is lost or wasted. In addition, the current food system has caused great damage to the environment, such as a large amount of greenhouse gas emissions, a sharp decline in biodiversity, and a large consumption of fresh water resources, which have further aggravated food insecurity, equity and sustainability of the food system have been devastated. Therefore, we urgently need to have a comprehensive examination of our current food system and establish an environmentally friendly and sustainable food system.

1.2 Our Task

Most of the current food system are dominated by profitability and efficiency. Consequently, a comprehensive examination of our current food system appears a reasonable and warranted endeavor. We should understand the mechanism and process of food production, supply-chain, consumption, and decomposition. We are supposed to consider the influence and interaction of various driving factors in the food system, establish an evaluation model of the current food system, and quantify its evaluation indicators. At the same time, our model needs to be robust enough to optimize for various levels of efficiency, profitability, sustainability, and/or equity. On this basis, here are the main tasks that our model should address:

1. On the basis of the existing model, we need to consider factors such as environmental protection and food security, and optimize the two indicators of equity and sustainability to obtain an improved system. Compared with the current system, we should analyze the factors that need to be optimized, and take into account the different real-time conditions of these optimized factors in diverse countries, so as to further analyze the time required to optimize the food system.

2. We improve the priority of the existing food system, and there will be improvements in equity and sustainability, but the country needs to invest more technology, money and other costs. We need to analyze the benefits and costs of optimizing the food system, and compare in developed and developing countries. In addition, we still need to consider the time required for these indicators to meet expectations.

3. Due to the differences in national conditions and social development status of developed and developing countries, we need to consider the promotion value and application prospects of the optimized food system in different countries, and analyze the scalability and adaptability of our model.

2 Assumptions and Justifications

In order to simplify the influencing factors, our team made the following reasonable assumptions without violating the actual situation.

1. In the food system of different countries, we generalize the types of food instead of targeting specific types of food.
2. We only consider the chain process from food production to decomposition, ignoring the process of recycling and processing food waste to reproduce.
3. For the human-driven factors of the food system, we establish a one-to-one correspondence with the mechanism process, and only consider the dominant factors of each process.
4. In our food system model, we do not consider the impact of natural disasters and extreme weather.

3 Notions and Symbol description

The following Table 1 lists some of the most variable definitions and symbolic representations in our paper. And there may be other variables, but they are only used in some special sections.

Table 1: Variable Definitions and Symbolic Representations

Symbols	***Definitions***
SA	Suitable for agriculture
MSA	Moderately Suitable for agriculture
UA	Unsuitable for agriculture
PF	Production food in input vector
SSF	Start of supply-chain food in input vector
ESF	End of supply-chain food in input vector
CF	Consumption food in input vector
DF	Decomposition food in input vector
$\boldsymbol{\alpha}$	Science and technology factors in driving matrix
$\boldsymbol{\beta}$	Social policy factors in driving matrix
$\boldsymbol{\gamma}$	Demographic and economic factors in driving matrix
$\boldsymbol{\sigma}$	Environmental factors in driving matrix
$\boldsymbol{e}$	Efficiency indicators in output vector
$\boldsymbol{p}$	Profitability indicators in output vector
$\boldsymbol{s}$	Sustainability indicators in output vector
$\boldsymbol{q}$	Equity indicators in output vector

4 Mechanisms and Data Driven Hybrid (MDDH)Food System Model

4.1 Agricultural Pattern Clustering Model

In the current world food system, people in many countries and regions in the world are still suffering from hunger, and food scarcity still exists. In order to study the current status of food systems in different countries and regions in the world, we select countries with different geographical locations and economic development levels for analysis. As different countries have different factors such as agricultural production level, agricultural planting area, and population, the food systems of different countries are also quite different affected by these factors. Therefore, we use these indicators to perform cluster analysis of different countries. First, we collect three sets of data for per capita arable land x_1 (unit: hectare), food yield per hectare x_2 (unit: kg/ha), and the proportion of agricultural added value to GDP x_3 (unit: %) in different countries in the world to describe the state of agricultural development of a country, and establish a national agricultural index vector:

$$National\_agricultural = (x_1, x_2, x_3) \tag{1}$$

Since different indicators have different orders of magnitude, we first perform normalization processing, taking the x_1 data as an example, namely:

$$x_{1i} = \frac{x_{1i} - \min x_1}{\max x_1 - \min x_1} \tag{2}$$

Among them,$\max x_1$,$\min x_1$represent the maximum and minimum values of x_1 data respectively, and perform the same processing on x_2 and x_3.

Next, perform cluster analysis on different sample vectors, and calculate the Euclidean distance between (x_{1i},x_{2i},x_{3i}) and (x_{1j},x_{2j},x_{3j}) two vectors:

$$d_2(x_i, x_j) = \left[\sum_{k=1}^{3} \left| x_{ki} - x_{kj} \right|^2 \right]^{\frac{1}{2}} \tag{3}$$

Based on this,cluster and obtain three sample classes(G_1,G_2,G_3),and the mean of each sample class is calculated:

$$\overline{x} = \frac{1}{3 \times num\_i} \sum_{x_{ij}} x_{ij} \tag{4}$$

Among them, num_i represents the number of vectors in each sample class.

According to the calculated value, we divide the world's countries into three types of suitable for agriculture (SA), moderately suitable for agriculture (MSA) and unsuitable for agriculture countries (UA), as shown in Figure 1.

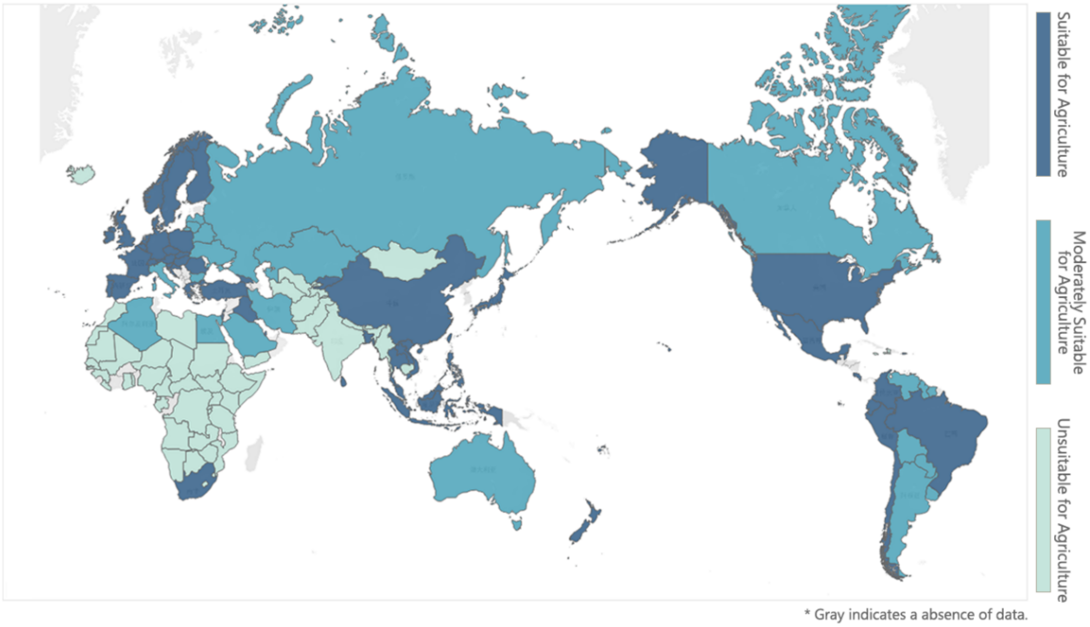

Figure 1: Three types of countries for agriculture

We select 123 countries in the world to analyze the development of their agriculture. After considering only the three factors mentioned above, we can get a preliminary clustering of different countries. China, the United States, Brazil and some Western European countries are suitable for agricultural production. Most areas in South Asia and Africa are not suitable for agricultural production, and places such as Canada and Russia are in between.

4.2 Food Mechanism Model

In order to further understand the existing food system and optimize it, we need to model and analyze the existing system. There are many complex related factors involved in the process of transporting food from farms to consumers, including the input, process and result of the food system. The food system is a complex social-ecological system involving multiple interactions between humans and nature. From the perspective of the mechanism of food, we divide the entire process of food into four subsystems: production, supply-chain, consumption and decomposition. Among them, the production subsystem includes the process from growing to harvesting in the farm. The supply-chain subsystem stage refers to the process of processing and transforming food into products, and going through the process of packaging, storage and transportation. At this time, the food products have been sent to the point of sale, and the consumption subsystem has undergone the process of retailing and the food products are consumed by consumers. In the end, some food may not be purchased by consumers and become spoiled and turned into food waste that needs to be further recycled. This subsystem is called decomposition. The complete food mechanism model can be shown as Figure 2.

Figure 2: Food mechanism model

In order to further quantify this mechanism model, we use the quality of food to describe the entire process. Because different countries have different areas, populations, and agricultural production policies, the total food output of different countries is different. We will focus on unit quality food (considered as one ton of food in this article) to study its mechanism in the food system. Because food flows into the system from the production subsystem, this subsystem is the starting point of the entire food system. We set the production food (PF) in the production subsystem as 1.

The food flowing out of the production subsystem enters the supply-chain subsystem. At the initial end of the supply-chain subsystem, the food flowing into the process (start of supply-chain food, SSF) can be equivalent to the food produced in the production subsystem:

$$SSF = PF \tag{5}$$

In this subsystem, food processing, packaging, storage and transportation are realized, and the process of food from farm to consumer is done. Therefore, it is the physical link of other subsystems.

Due to the influence of factors such as agricultural production levels and agricultural development in different countries and regions, countries have different food import and export policies. Based on this, we divide the world's countries into food importing countries, food exporting countries and food self-sufficiency countries. We use Trade Food to represent the amount of food imported and exported in food trade with other countries. When food is imported, the value of Trade Food is positive, when food is exported, the value of Trade Food is negative, and when food is self-sufficient, the value of Trade Food is zero. But in most cases, a country will import and export different food, so we use imports minus exports to get Trade food. Similarly, we use the ratio of Trade Food and the actual food in the production subsystem to obtain the relative amount of imported and exported food (TF), then in the supply-chain subsystem, the end of supply-chain food (ESF) can be written as:

$$ESF = SSF + TF \tag{6}$$

After the supply-chain subsystem, the food will flow into the consumption subsystem to become Consumption Food (CF), where it is purchased and eaten by consumers. Markets, informal retail, street vendors, supermarkets and small stores are where the majority of the world's population acquires their food and they are also a core component of the subsystem. However, a part of the food does not flow into the consumption subsystem, but spoils and turns into food waste, and enters the decomposition subsystem to become Decomposition Food (DF), then the three variables satisfy the relationship:

$$ESF = CF + DF \tag{7}$$

Decomposition subsystem food can be transformed into fertilizer after garbage recycling and processing, and then enter the production subsystem again. In order to simplify the calculation, we will only consider the chain structure of the food from the production subsystem to the decomposition subsystem when building the food system below, without considering the food recycling process.

4.3 Driving Factors of Food System

In the mechanism process of the food system, a variety of interactions between man and nature are involved. In order to better establish a food system, it is necessary to understand these man-made driving factors and the mutual influence of various factors. We divide these factors into four dimensions: science and technology factors, social policy factors, demographic and economic factors and environmental factors, as shown in Figure 3. The above four factors can affect all processes from food production to decomposition, but in order to make the food system model clearer and more intuitive, we only consider the dominant factors of each mechanism process.

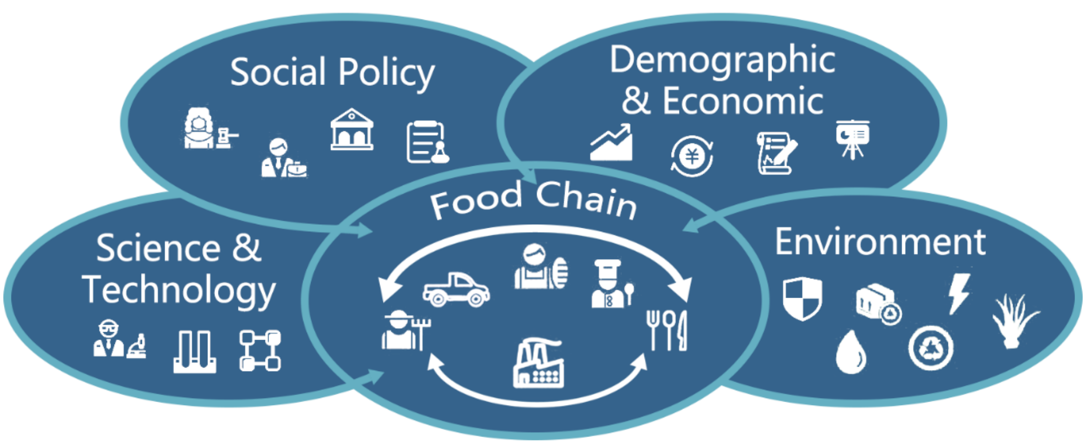

Figure 3: Driving factors of food system

- Science and technology factors(α)

With the advancement of science and technology, more and more countries in the world are adopting advanced scientific and technological means to improve their own agricultural production levels. Mechanized planting methods can save a lot of labor, improve production efficiency, and cultivate advanced and improved varieties to shorten planting time, increase production, increase the nutritional value of food and so on.

- Social policy factors(β)

We closely integrate social policy factors with the supply-chain process. Related policies formulated by the state play a vital role in the distribution and transportation of food. At the same time, the country's macro-control directly affects the import and export trade of food. For example, some countries still have amounts of people in hunger, but the pursuit of exporting food for higher profits has seriously endangered food security. Besides, social culture, religion and other factors also affect the process of food processing and distribution.

- Demographic and economic factors(γ)

Demographic and economic factors are closely related to the consumption process. The number of people in a country and the level of economic development directly affect the purchasing power and consumption level of food. The age structure of the population, population growth rate, migration rate and other factors also affect food consumption.

- Environmental factors(σ)

The existing food system has caused serious damage to the environment, and environmental factors have further attracted more and more attention from countries. In this article, we closely integrate environmental driving factors with the decomposition and recycling process of food. Environmental treaties and related restrictive factors will affect the recycling and processing of food waste.

4.4 Food System Matrix Model

With the increase in population and the harsh environment, the evaluation and optimization of the existing food system has become increasingly critical. We evaluate the existing system through four indicators of efficiency, profitability, sustainability, and equity. First, we use data to quantify the above four indicators.

- Efficiency

Efficiency can be expressed as the time consumed by the mechanism process of food, or as the number of laborers consumed by the process. In this model, we use the number of people to quantify efficiency, considering all the mechanisms of food from production, supply-chain, consumption to decomposition. The number of laborers consumed by the process is represented by e_{num}, and the number of laborers consumed by each process is represented by e_1,e_2,e_3,e_4 (unit: person/ton), which can be expressed as:

$$e_{num} = e_1 \times PF + e_2 \times SF + e_3 \times CF + e_4 \times DF \tag{8}$$

- Profitability

We use money to quantify profitability. We consider the profit amount of the entire mechanism process as p_{num}. The amount of money earned or lost in each process is represented by p_1,p_2,p_3,p_4 (unit: USD/ton), and the income is represented as a positive value, while the expenditure is expressed as a negative value:

$$p_{num} = p_1 \times PF + p_2 \times SF + p_3 \times CF + p_4 \times DF \tag{9}$$

- Sustainability

Sustainability is an attribute of the system, and its interaction with the outside world is open. Over time, the system can maintain its inherent identity and stability. Based on this, we proceed from the environmental point of view, consider the impact of the mechanism process of food on the ecosystem, and use carbon dioxide emissions as a quantitative indicator. Carbon dioxide is a greenhouse gas, and in recent years, the amount of carbon emissions in the environment has been increasing, posing a great threat to our environment. We use s_{num} to represent the amount of carbon dioxide emitted during the whole process from food production to consumption, and s_1,s_2,s_3,s_4 (unit: kg/ton) to represent the amount of carbon dioxide emitted by each process:

$$s_{num} = s_1 \times PF + s_2 \times SF + s_3 \times CF + s_4 \times DF \tag{10}$$

- Equity

In the world, the food produced is enough to feed everyone, but the food and the technology to produce food do not always reach the people who need it. At present, the problem of food insecurity and malnutrition in the world is still very serious. The current food insecurity in the world is mainly due to the following reasons: extreme weather, social unrest, economic slowdown, and food waste. In order to quantify this process, we use the incidence of malnutrition in different countries q_{num} to describe the severity of food insecurity. In the process of food mechanism, we use the ratios of extreme weather, social unrest, economic slowdown, and food waste q_1,q_2,q_3,q_4 (unit: %/ton) to indicate the contribution rate to food insecurity:

$$q_{num} = q_1 \times PF + q_2 \times SF + q_3 \times CF + q_4 \times DF \tag{11}$$

In the above description, we have established the relationship between each indicator of efficiency, profitability, sustainability, and equity and the four subsystems of production, supply-chain, consumption and decomposition. If the above mathematical formula is processed, the matrix model of the food system can be obtained:

$$\begin{bmatrix} e_{num} \\ p_{num} \\ s_{num} \\ q_{num} \end{bmatrix} = \begin{bmatrix} e_1 & e_2 & e_3 & e_4 \\ p_1 & p_2 & p_3 & p_4 \\ s_1 & s_2 & s_3 & s_4 \\ q_1 & q_2 & q_3 & q_4 \end{bmatrix} \cdot \begin{bmatrix} PF \\ SF \\ CF \\ DF \end{bmatrix} \tag{12}$$

Analyzing the above food system model, it is not difficult to find that when the food quality of the four mechanisms of food is given, the quantitative index of its output is fixed, but in fact, the actual food system is a complex social-ecological system, involving multiple interactions between man and nature. Combining the four driving factors we considered above with the food system, when the quality of the food is given in the mechanism process, but if the driving factors change and interact, the indicator output will also change. The complete food system model is shown in Figure 4.

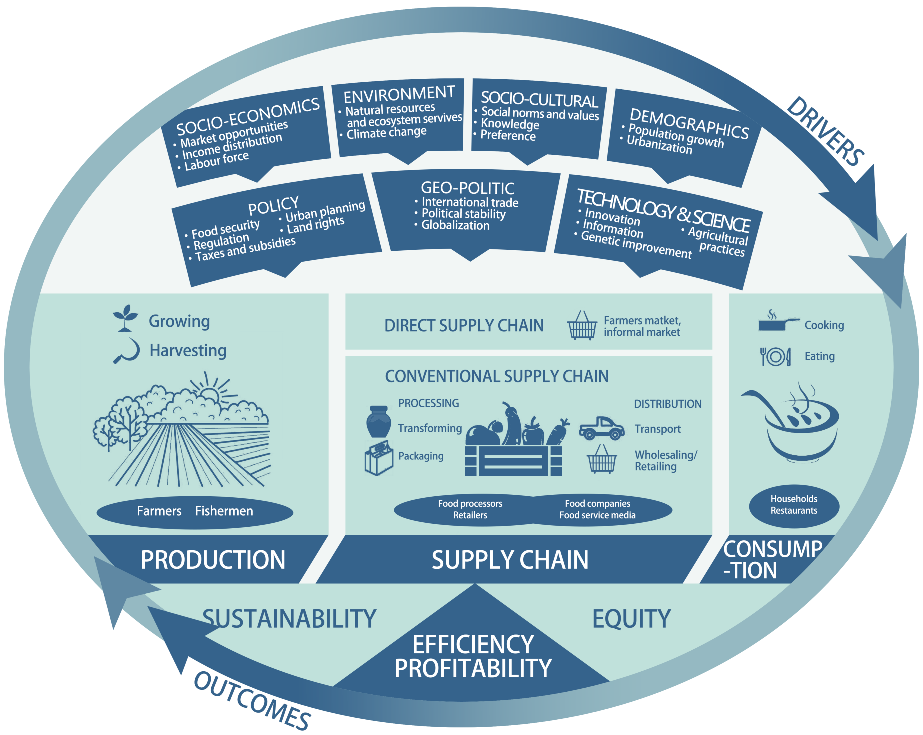

Figure 4: Food system model

Considering the influence of driving factors, we need to adjust the above model. It is not difficult to find that the dimensions of the quantitative indicators of the above models are different, and the magnitudes of their output values are also different. Therefore, it is difficult for us to intuitively compare the relative sizes of the indicators. We improve the above evaluation indicators. The ratio of agricultural employment to the country's total employment population and the ratio of agricultural production GDP to national GDP are used to describe efficiency and profitability. When these two ratios are larger, it means that the country's agricultural production efficiency and profit are higher. At the same time, we describe sustainability and equity through the ratio of agricultural production carbon dioxide emissions to the country's total carbon dioxide emissions and the national malnutrition rate mentioned above. The lower these two ratios, the better the environmental protection and food security of the country's agricultural production. In order to compare the data more intuitively, we reverse these two ratios and subtract these two values from 1. That is, the larger the four percentage values, the better the corresponding indicators. We use e_{ratio},p_{ratio},s_{ratio},q_{ratio} respectively to indicate these four ratios.

In the above discussion, we described the effects of $\alpha, \beta, \gamma, \sigma$ on PF,SF,CF,DF, and at the same time have an impact on four evaluation indicators. We get the following improved matrix model:

$$\begin{bmatrix} e_{ratio} \\ p_{ratio} \\ s_{ratio} \\ q_{ratio} \end{bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} & \alpha_{14} \\ \beta_{21} & \beta_{22} & \beta_{23} & \beta_{24} \\ \gamma_{31} & \gamma_{32} & \gamma_{33} & \gamma_{34} \\ \sigma_{41} & \sigma_{42} & \sigma_{43} & \sigma_{44} \end{bmatrix} \cdot \begin{bmatrix} PF \\ SF \\ CF \\ DF \end{bmatrix} \tag{13}$$

Based on this, we re-describe the food system. We call the food mechanism process Input Vector, where PF is still taken as 1, while SF, CF, and DF vary due to the change of each country's food import and export ratio and the proportion of food waste. We call the indicator output vector of the system Output Vector, and the four output ratio values reflect the four performances of the food system: efficiency, profitability, sustainability, and equity. We call the intermediate process Driving Matrix, which reflects that for a given input vector, the output ratio index is obtained after the driving factor acts. The mechanisms and data driven hybrid model of the entire food system is shown in Figure 5.

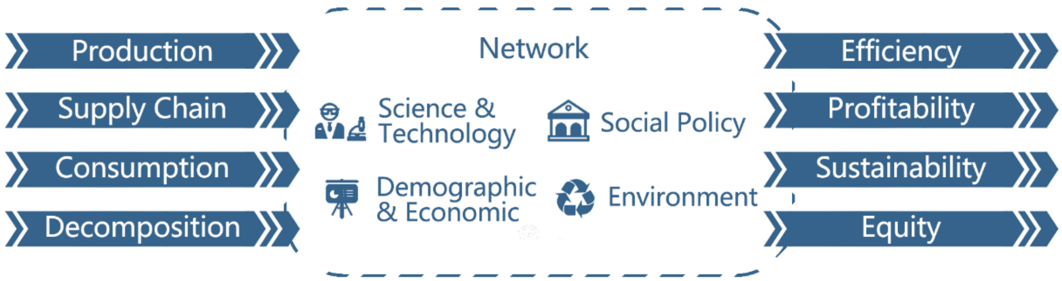

Figure 5: MDDH food system model

All above, Driving Matrix is also a performance indicator that reflects different food systems and reflects the internal function of the food system. We can equate it to a "black box". Based on the mechanism model, the Driving Matrix is obtained through a data-driven method. In order to obtain the ideal output, we can modify the Driving Matrix and describe it in a macroscopic way.

4.5 Three Types of Food System

We collect data such as food import and export rates, food waste rates, and national malnutrition rates in different countries and regions in different years, and process them to obtain multiple sets of input and output vectors. According to multiple sets of data of a country in different years, for each evaluation index, it can be expressed as four input linear function expressions. Taking efficiency as an example, it can be written as:

$$f(PF, SF, CF, DF) = \alpha_{11} \times PF + \alpha_{12} \times SF + \alpha_{13} \times CF + \alpha_{14} \times DF \tag{14}$$

We use the data of different years to perform multiple linear fitting, using the least squares fitting criterion:

$$J(\alpha_{11}, \alpha_{12}, \alpha_{13}, \alpha_{14}) = \sum_{i=1}^{n} \delta_i^2 = \sum_{i=1}^{n} [f - e_{ratio}]^2 \tag{15}$$

Relevant fitting coefficients are obtained. Similarly, according to this method, fitting coefficients of other indicators can also be obtained, and finally 16 parameters of Driving Matrix can be obtained. This process is based on the previous mechanism model, through a data-driven way to obtain the Driving Matrix of the food system.

In addition, we can also use the above method to obtain the Driving Matrix of different countries. Through comparison, we found that according to the cluster analysis above, the Driving Matrix of the food system of the same category of countries has a strong similarity. Based on this, we classify the food systems of different types of countries. We call them traditional food systems, moderate food systems and modern food systems. Their characteristics are shown in Table 2:

Table 2: Three Types of Food System

	Traditional	Moderate	Modern
Production	Low level of science and technology	A mixture of mechanical and manual	Small to industrialized; global production
Supply-chain	Lack of adequate infrastructure	Social policy support	Efficient and perfect supply system
Consumption	Low diversity, limited food retails shops	Greater diversity of markets	High level of consumption
Decomposition	Low efficiency and high environmental cost	Subject to environmental factors	High recycling efficiency and environmental protection

4.6 MDDH in different countries

According to our cluster analysis, both China and the United States are suitable for agriculture, and the two belong to developing countries and developed countries respectively. Therefore, we will apply our food model to two countries to illustrate. First, we collected data on the import and export rate of China and the United States from 2001 to 2018, the ratio of agricultural employment to the country's total employment, and the ratio of agricultural production GDP to the country's GDP. Substituting them into the model, we obtain the Driving Matrix of China and the United States, and their visualization results are shown in Figure 6.

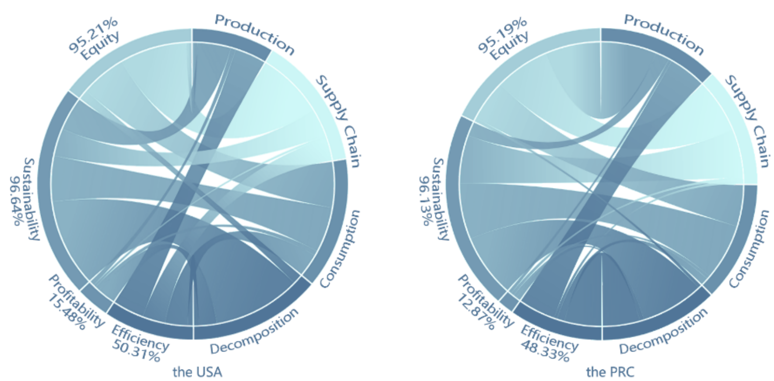

Figure 6: MDDH Model in the USA and the PRC

We can think of Driving Matrix as the embodiment of the national food system. The figure shows the relationship between the four subsystems of production, supply-chain, consumption and decomposition on the output of the four indicators. The connections can represent the role of driving factors. Compared with China, the United States has higher agricultural profit and efficiency, and the expression of technological factors in the four indicators is more even. China's demographic, economic and environmental factors play a large role in sustainability indicators. The level of scientific and technological development of the two countries is at the forefront of the world, so the food security of the two countries is relatively good. Considering the actual situation and future development trends, the sustainability and equity of the food systems of the two countries can be further improved.

5 Optimized for Equity and Sustainability (OES) Food System Model

5.1 Optimized for Equity and Sustainability

At present, most countries' food systems are still dominated by profitability and efficiency, and there is still a lot of room for improvement in the environment and food security. Based on this, we hope to further improve the sustainability and equity of the system under the premise of ensuring profitability and efficiency. We still use s_{ratio} and q_{ratio} to quantify these two indicators and establish a simple single-objective optimization model. We are here only considering the sum of s_{ratio} and q_{ratio} to be the maximum, that is, the entire optimization model is expressed as follows:

$$\max(s_{ratio} + q_{ratio}) \tag{16}$$

$$s.t \begin{cases} SSF + TradeFood = ESF \\ PF = 1 \\ ESF = CF + DF \\ \frac{DF}{ESF} \leq WASTE_{\max} \\ |TradeFood| \leq Trade_{\max} \\ \sum_{i=1}^{4} \alpha_{ij} = 1(j = 1, 2, 3, 4), \alpha_{ij} \geq 0 \end{cases} \tag{17}$$

In our model, the value of the input vector can be changed. In the SF process, Trade Food can participate in the optimization considering the import and export of food, but there will be an upper limit on the ratio of import and export, which depends on the policies of different countries. in addition, the distribution ratio of food can also be changed, that is, the ratio from ESF to CF and DF is not fixed. During the optimization process, based on the actual situation, we also made corresponding restrictions on the Driving Matrix. Considering that each column of the matrix represents the influence of the driving factor on the four indicators, we limit the algebraic sum to one, and the numerical value indicates the relative influence of the driving factor on the four output results. In addition, the size of the factor should be between zero and one.

We brought the data of China and the United States into our optimized model, and the output results are as shown in Figure 7:

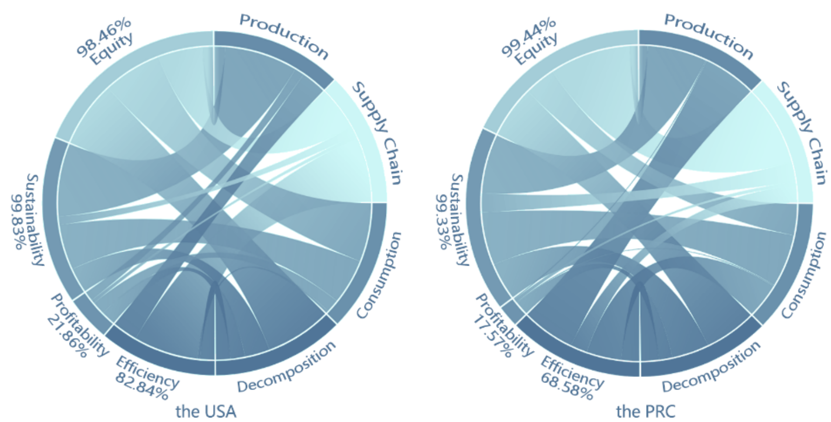

Figure 7: Optimized model of America and China

By bringing the data of China and the United States into the optimization model, we find that sustainability and equity have been significantly improved. The equity and sustainability of the United States can reach 98.46% and 99.83% respectively, and the proportion of China can reach 99.44% and 99.93%, meaning that the incidence of malnutrition in the two countries can be further reduced. The failure to reduce to 0 may be caused by the physical characteristics of some of the populations, and external factors have reached the ideal state. At the same time, under ideal conditions, the proportion of carbon dioxide emissions from agricultural production in total carbon dioxide emissions will also drop further.

In addition, from the comparison of the models before and after optimization, we find that while equity and sustainability have been improved, the evaluation indicators of efficiency and profitability have also been further improved. From the perspective of the driving factors of the food system, the two countries' science and technology, policy, economy, environment and other factors are more invested in the two indicators of equity and sustainability. From the perspective of macro-control, the food system puts more emphasis on food security and environmental protection.

Considering different indicators, the improvement of food equity in the United States mainly depends on changes in environmental and economic driving factors, while the improvement of China's equity depends more on the improvement of food packaging, storage, distribution and other supply-chains. Considering the actual situation, the United States, as a major agricultural country, has a leading position in the world in terms of agricultural production efficiency of its mechanized operation mode, and its annual food output is sufficient for people to eat. Therefore, adjustments to environmental and economic factors are more conducive to maintaining food security. Although China has a large population, its improved agricultural production methods have significantly improved its efficiency. However, China has a vast territory, and the population density and food production are unevenly distributed between the east and the west, the north and the south. Therefore, further optimizing the supply system can improve the efficiency of food distribution and maintain food security.

Based on the consideration of the sustainability of the food system, the improvement of the environment in the United States depends more on its technological driving factors. The scientific and technological development level of the United States is among the highest in the world, and it is more necessary to use it for environmental protection, using advanced scientific and technological means to reduce environmental damage caused during food production, which is conducive to the sustainable development of the environment, while China has a large population and a huge amount of food consumption, the annual waste on the table is also a huge number. Through some control measures, taking into account demographic and economic factors, reducing waste caused in the consumption link will be more conducive to environmental protection, maintaining the sustainability of the food system.

5.2 Time for Implementation

After a long period of development and evolution, the food systems of different countries are now in a relatively stable stage, affected by natural and social factors such as extreme weather, social unrest, and economic slowdown. At present, many countries and regions in the world still have food insecurity and other problems. If we want to make adjustments and improvements to the food system, we need to consider from the perspective of many driving factors such as science and technology, social policies, population economy, and the environment. Considering the development status of different countries, it is necessary to formulate adjustment policies that suit their own national conditions. The length of time these driving factors act in the mechanism of food varies. Therefore, the time required for system implementation depends on different driving factors. The duration of the mechanism process depends on a series of comprehensive factors such as the country's development level and national policies. Considering that the indicators in the Driving Matrix are qualitatively analyzed and difficult to quantify, we choose to make gray predictions on the import and export values of the Input Vector. First, find the ideal optimal value according to the optimization model mentioned above. At this time, it corresponds to an optimal Input Vector, from which we can obtain relevant data such as the amount of food imported, the rate of food waste, and so on. The export ratio changes year by year and will not change drastically in a short period of time. We make predictions based on the actual situation. The import and export rate are expected to be about 10%. Then we can infer the time required to reach the ideal import and export ratio based on the import and export ratio from 2001 to 2018. The forecast result is shown in Figure 8:

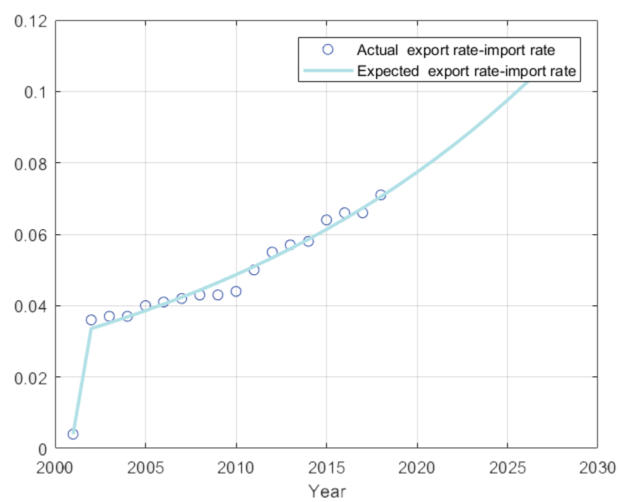

Figure 8: Export rate-import rate prediction analysis

According to the fitted function and graphical trend, the relationship between the import and export rate and the year is similar to an exponential growth. In order to achieve the expected import and export rate of 10%, the estimated time span is 6 years, that is, starting from 2018, after six years of development and evolution, the expected goal can be achieved, which means that such a system will take 6 years to implement.

5.3 Benefits and Costs Analysis

Based on the improvement of the existing food system, by adjusting the influence of various driving factors and their interaction, we can optimize the Driving Matrix of the existing food system, and optimize the driving coefficient under the premise of given input, making its output value present the best. At the same time, from a system perspective, we can also change the value of the Input Vector to make the output reach the best state. Through adjustments, we find that the improved sustainability index of the food system and the equity index of the food system have been further improved, which means that the proportion of the country's undernourished population will drop to zero. At the same time, the amount of carbon dioxide emitted by the food mechanism process will be further reduced, which is conducive to the establishment of an environmentally friendly food system.

But at the same time, the model of the food system we currently build is based on data-driven. First, according to the actual development of different countries, a large amount of data calculation and training are required to get the appropriate driving factors. The computational cost and time cost of this process have been greatly increased. Without considering these costs, we found that the profit of the optimized model further increased. However, we need to calculate the time, manpower, material resources and other resources consumed in this process to calculate the profit. In addition, changing the priority of the food system requires a large amount of input from social and human factors. In this process, the mutual influence of different factors needs to be taken into consideration. Forcible adjustments to the original food system require national or regional macro-control.

Based on the previous cluster analysis, we analyze the optimized results of the sustainability and equity of the food system in three different types of countries. We train through a large amount of data, and finally go to the average results for many times. We find that there are differences in the optimal value that different types of countries can achieve, as shown in Table 3.

Table 3: The sustainability and equity of different countries

Type	Country	Sustainability	Equity
	Japan	99.67%	98.56%
I	Thailand	98.44%	99.65%
	Denmark	99.32%	99.12%
	Ukraine	98.44%	98.97%
II	Canada	98.74%	98.88%
	Argentina	97.96%	98.03%
	India	97.77%	96.86%
III	Jamaica	97.56%	96.74%
	Nigeria	96.89%	97.07%

In the optimization process, we do not consider the mutual restriction of the internal factors of the Driving Matrix, and only limit its Input Vector. We find that the first category is countries suitable for agriculture with a higher optimization upper limit, while the third category is countries not suitable for agriculture, and the optimization value is slightly lower than the first two categories of countries. The main reason for this phenomenon is the limitation of the import and export ratio of different countries and the limiting factors of food waste rate. These factors are based on the actual conditions of different countries.

The above values are theoretical values and the maximum values that can be reached under ideal conditions. However, in fact, many social and human factors must be considered. These are different in developed and developing countries. The driving factors we consider are mainly science and technology, social policies, demography, economy, environment and many other factors. These factors may have formed a relatively complete system in developed countries, but still need to be continuously improved in developing countries. Therefore, the time cost for improving the food system is different. Secondly, making optimizations to the existing food system requires a lot of calculations, and the level of scientific and technological development between developed countries and developing countries is also different. In addition, in the above optimization process, we only consider the equity and sustainability indicators of food, and do not restrict profitability and efficiency. Therefore, for some developing countries, while pursuing equity and sustainability, profitability and efficiency will drop significantly. Regarding the situation of China and the United States above, the theoretical maximums of profitability and efficiency of the two countries have both increased slightly. The reason is that the food systems of the two countries have been relatively complete, and the various driving factors we consider are also relatively mature. Therefore, when making changes to the food system, while pursuing the maximization of sustainability and equity, it is also possible to take into account both efficiency and profitability.

5.4 Gray Forecast Model for Sustainability and Equity

In order to make the food system take environmental friendliness and food security as the leading factors, we have made the above model research and optimization, and based on the actual situation and results, we have made the expected environmentally friendly indicators and expected food security indicators. We further connect with reality and delve into the expected year of this indicator. We use the gray forecast model analysis model to bring the environmental friendliness indicators and food security indicators from 2001 to 2018 into the following steps respectively, and we can predict the best years required for the realization of these two expectations. The specific steps of gray forecast model are as follows:

- Step1: Generate a new data matrix (the first data of the new data matrix is the first data of the original data matrix, and the second data of the new data matrix is the second data of the original data matrix plus the second data of the new data matrix and so on.)
- Step2: Perform calculations on the new data matrix immediately adjacent to the mean value and replace the values in the original position of the new data matrix.
- Step3: Use the least square method to get the linear fitting function of the new data matrix. The resulting images are as follows:

- Step4: Predict the follow-up data and get the expected environmental friendliness, food security indicators and the corresponding time points.

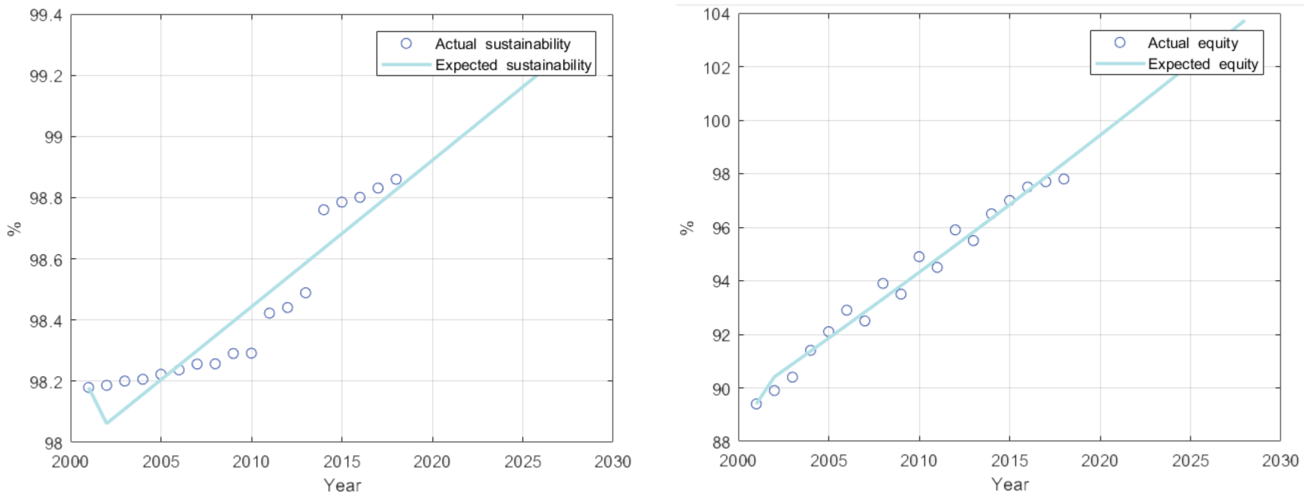

Figure 9: Gray forecast model of sustainability and equity in developed countries

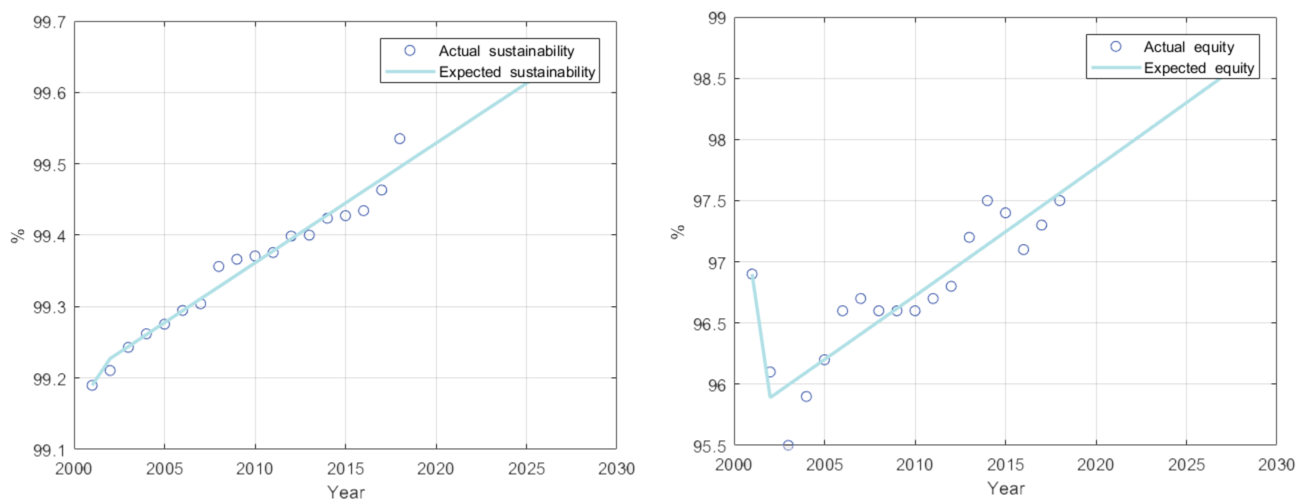

Figure 10: Gray forecast model of sustainability and equity in developing countries

According to the graph and the fitting function, it can be concluded that the sustainability and equity are required to achieve the expected results (compared to the data in 2018, the sustainability and equity are increased by at least 0.1%). It can be seen from the figure that it takes at least 9 years for developing countries, while developed countries need at least 4 years. In actual production and life, there is a certain time gap between the promulgation and implementation of science and technology and policies. The length of this time gap is related to many factors in the country. According to the slope of the predicted curve in the figure, it can be seen from the side that developed countries have more advantages in development than developing countries.

6 Regional model validation

Make the following assumptions:

- An area composed of multiple countries is defined as a large region, and an area of a certain state/province is defined as a small region.
- Whether it is a large region or a small region, factors such as technology, policy, and economy within the area are connected closely.
- The import and export trade exchanges between countries map to the trade exchanges between large regions, and the intra-regional trade exchanges are not counted. The import and export trade flows between countries is equivalent to the transportation between small regions.

In response to the assumptions above, in order to test the scalability and applicability of the Driving Matrix model, we apply it in Asia (a large region) and Henan Province of China (a small region). We apply the same method to construct the of large region and small region. The steps are as follows:

- Step1—Data preparation: Look for quantitative data indicators including production, transportation, sales, decomposition, efficiency, profitability, sustainability and equity in several major countries in Asia (counties of Henan Province, China) from 2001 to 2018. The sum of the same category is performed, and finally the four input indicators of the result are normalized. Then the four output indicators are percentageized.
- Step2—Model construction: Encapsulate the four input indicators and four output indicators into a matrix, and predict the influence factors in the Driving Matrix to a certain extent.
- Step3—Solving model: Use evolutionary algorithm to calculate the Driving Matrix, get the Driving Matrix closest to the ideal output, and assign the influence factors and weights to the matrix.
- Step4—Output optimization: Improve the expected results of two output aspects of sustainability and equity, and use the evolutionary algorithm to optimize the Driving Matrix again. Then compare the results with the original results. After that, find the most suitable decision based on quantitative data.
- Step5—Gray Forecast Model: Construct a gray forecast model to predict the expected target, compare the system implementation time, and compare the influence of regional factors on the time.

It should be noted that due to the influence of regional geographic factors, the size of the region will have a significant impact on the scale of imports and exports, and the speed of widespread popularization similar to technology and policies will have a significant downward or upward trend.

Model verification results analysis report: In the original food system, the output of profitability, sustainability and equity in the large area and the small region is not much different from the output data of the food system constructed by the model. In terms of technology and policy, the large region and the small region have increased by 11.31% and 4.83% respectively compared to the original system. However, the efficiency of the comparison output, due to distance, the value in the large region model has dropped by 42.89 %, and only increased by 0.04% in a small region. In the model results of gray coast prediction, the realization time of the large region model is 27 years, while the small-area model only takes 6 months. Based on the above analysis, we conclude that the model we built has wide applicability in a small region, and can predict the development of food in the area based on the model data and make certain reasonable optimizations. For the large region model, distance factor has become an element that cannot be ignored, so our model is not completely applicable in large regions, but some parameter models that do not take distance as the dominant factor can still be measured.

7 Sensitivity analysis

7.1 The influence of production factors in the mechanism process on the model

Minor changes to the production model in the mechanism process will affect the transportation, sales and decomposition after the mechanism process. We increase the production input in the mechanism model by 10%, and then go through the above cluster analysis and evolutionary algorithm, grayscale analysis and other processes, to examine the impact of small changes in production inputs on the applicability of the model. We take the model of developed countries as the test object. Due to minor changes in production input, under the original food system, without changing the Driving Matrix, according to the mathematical model, we can calculate the output model corresponding to the change in production input. The output of the model is as shown below:

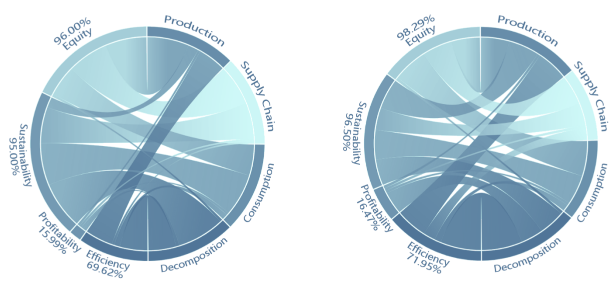

Figure 11: Sensitivity analysis model (Production improvement)

Comparing the output of the model with the output of the original grain system, it is calculated that the output fluctuates within 0.48% 2.29% on the basis of the original system, which shows that under the condition that the parameters of the food system remain unchanged and the small production input model changes, the impact on the output is negligible, and the food system model is less sensitive to changes in production factors.

7.2 The influence of food waste in the mechanism process on the model

We considered the phenomenon of food waste in the mechanism process, which will have a certain impact on the distribution of food. The model of developed countries is also used as the test object. Through reading the data, the food waste rate in developed countries has accounted for about 30% in recent years. Based on the collected data for many years, we have increased the data by 10%. In addition, the input indicators after changing the data are brought into the original food system model, and the output quantitative indicators are compared with the original output indicators. The output model based on the changed input is as follows:

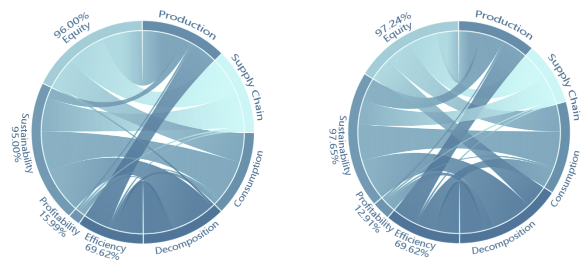

Figure 12: Sensitivity analysis model (Waste rate increased)

After comparing the models, we found that the output of the changed output is different from the output of the original food system, and the output indicators have different degrees of deviation, mostly within the range of 3% deviation. Therefore, the food system is not sensitive to food waste factors.

8 Strengths and Weaknesses

8.1 Strengths and Innovations

1. Constructed a Driving Matrix that maps from the mechanism process to efficiency, profitability, sustainability and equity under the influence of factors such as science and technology policies, and can predict the output results based on the matrix under different input conditions in the same country.

2. This article uses evolutionary algorithm to calculate a variety of possible results for matrix operations, and compares different results. Therefore, the results obtained are more realistic.

3. This article gives the specific optimization measures used to optimize the food system, and gives a detailed description of the specific consequences of these measures.

4. This article uses the gray forecast model to make specific predictions on carbon dioxide emissions and food nutritional value, and gives the expected time and cost of specific model construction.

5. The model constructed in this article has a wide range of application areas and is suitable for model construction in small and medium-sized areas, and can calculate and compare relevant parameters for a certain large area.

8.2 Weaknesses

1. The model constructed in this article fails to take into account the factors of distance, so the model construction in a large area is not ideal.
2. Due to limited data, it is not possible to make accurate predictions of incentive factors.
3. Due to the limited time and space of the article, it is not possible to cite long-length data for listing and proof.

8.3 Improvement

1. Factors such as distance are also considered in the model, and the model is optimized to make the model cover a wider range.
2. Expand the scope of data to make the factors considered more comprehensive.

9 Conclusions

With the increasingly severe problems of food security and environmental pollution, it is necessary to optimize the current food system for various levels of efficiency, profitability, sustainability and equity. In this article, we have established a Mechanisms and Data Driven Hybrid (MDDH) Food System Model by analyzing the food systems of countries in the world. On this basis, we obtained the Optimized for Equity and Sustainability (OES) Food System Model.

- We analyzed the food systems of different countries and divided them into three categories through cluster analysis. By establishing the mechanism model of the food system and combining the data-driven method, we obtained a Driving Matrix describing the food system. Taking China and the United States as examples, the food systems of developing and developed countries could be simulated by this model.
- Through the single-objective optimization model, the sustainability and equity of the optimized food system have been significantly improved. If actual factors are considered, the efficiency and profitability of the optimized food system will be affected to a certain extent, and the degree of influence is different in different countries.
- By optimizing the food system, the environment and food security in different countries will be significantly improved, but applying this food system model will generate a lot of calculations and consume a lot of time. For developed countries, it takes at least 4 years to the optimized system to generate benefits, and for developing countries, it takes at least 9 years.
- Through the analysis of countries with different levels of agricultural development in the world, our food system model had scalability and scalability. By slightly adjusting the food import and export rate and other parameters, the model did not change drastically, indicating that our model was stable.

10 Reference

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